Study on Flow Model for Binghamian Grouts in Tilted Single Fracture

その他（別言語等）のタイトル	傾斜した亀裂内でビンガム流体状グラウトの流れモデル
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Study on Flow Model for Binghamian Grouts in Tilted Single Fracture

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In accordance with the Navier-Stokes equation between planar plates, the equation of motion of the Binghamian grouts is deduced in smooth and inclined fissures. The model indicates that the velocity of flow gradually reduce with the development of time. And the greater the pressure is, the greater the speed is, as a result, the Binghamian grouts has a further infiltration. The velocity of flow of Binghamian grouts has nothing to do with fissure inclination. In addition, in the circumstance of the same parameters, the wider the fissure is, the slower the velocity of flow of Binghamian grouts is; the bigger the viscosity of grouts is, the slower the flow is; the smaller the initial shear strength is, the slower the flow is; the bigger the Binghamian grouts density is, the slower the flow is; and vice versa.

Keywords: Fractured rock mass, Grouting, Flow model, Binghamian grouts

1 INTRODUCTION

Because of the complicated distribution of fractures in crude rock mass, at present, the fractured rock mass grouting theory only limits to study on the seepage law of grouts in single smooth fracture. Assuming that the grout is Newton fluid, many scholars study the penetration law of grouts in cracks. Liu Jiacai[1] derived the diffusion equation of the Newton grouts radial flow along the fracture surface. Baker[2] assumed that the grouting hole horizontally passes through a smooth fracture; at last, he obtained the penetration law of Newton grouts by Graphic method. In addition, Wittke[3], Lombardi G[4] and Amadei[5] studied the flow law of Binghamian grouts in fractures. But their researches ignored the influence of fracture angle on penetration law of Binghamian grouts. This paper detailedly studies the influence of fracture angle on the seepage law of Binghamian grouts.

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2 THEORETICAL STUDY ON FLOW MODEL

The rheological curve of Binghamian grouts is not a straight line through origin of coordinate. It is a typical plastic fluid. When its yield stress is not less than the applied shear stress, it appears a deformation which is similar to the elastic deformation of solid. Only when the shear stress exceeds the yield stress of Binghamian grouts, the grouts can flow. Its rheological equation is [6]:

$$\begin{array}{lll} \text{when} & \tau > \tau_0 & \tau = \tau_0 + \mu_\infty \dot{\gamma} \\ \text{when} & \tau \le \tau_0 & \dot{\gamma} = 0 \end{array} \qquad (1)$$

Where τ is the shear stress of Binghamian grouts, $\dot{\gamma}$ is the shear rate corresponding to τ, τ_0 is the initial shear strength and μ_∞ is the ultimate strength.

Most clay slurry, some chemical grouts and the cement grouts that of W/C ratio is less than 1.0 also belongs to Bingham fluid.

On the assumption that grouts flow between two smooth parallel plates of infinite length, b is the spacing of the two plates, θ is the inclination, r_0 is the radius of grouting hole, and y_b is the radius of flow core. The diffusion model is displayed in Fig.1. Based on the differential momentum equations of incompressible viscous fluid in the Cartesian coordinate system, the flow equations in the x-direction yield:

Differential continuity equation:

$$\frac{\partial u}{\partial x}=0 \tag{2}$$

Differential momentum equation:

$$\rho\frac{\partial u}{\partial t}=\rho g_x-\frac{\partial p}{\partial x}+\frac{\partial \sigma_x}{\partial x}+\frac{\partial \tau_{xy}}{\partial y} \tag{3}$$

Constitutive equation:

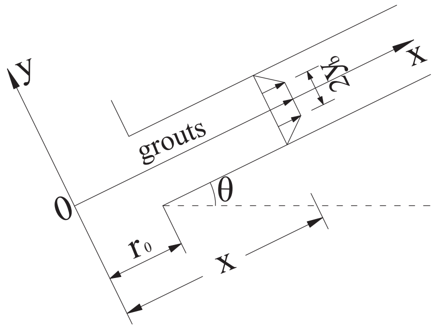

Fig.1 Diffused model of grouts in tilted single fracture

$$\sigma_x=-(p-\tau_0) \tag{4}$$

$$\tau_{xy}=\tau_0+\mu\frac{\partial u}{\partial y} \tag{5}$$

Where u denotes the velocity of grout in the x-direction, ρ is the density of grout, g_x is the weight component of unit mass of grout in the x-direction, σ_x and τ_{xy} are the stress components borne by grout in the unit area, μ is the dynamic viscosity, τ_0 is the initial shear strength of grout, p denotes the pressure borne by grout.

On the basis of above definition, giving:

$$g_x=-g\sin\theta \tag{6}$$

Because the grouting has a longer period, $\partial u/\partial t$ can be neglected, combination with Eq.(6), thus, Eq.(3) becomes:

$$\frac{d(p+\rho g x\sin\theta)}{dx}=\frac{d\tau_{xy}}{dy} \tag{7}$$

Here we introduce a parameter p*:

$$p^*=\rho g(h+x\sin\theta) \tag{8}$$

Integrating the Eq.(7), and taking into account the symmetry, using τ_{xy}=0 at y=0, thus Eq.(7) becomes:

$$\tau_{xy}=\frac{dp^*}{dx}y \tag{9}$$

Combination with Eq.(5), Eq.(9) takes the form:

$$\tau_0=\rho g(J-\sin\theta)y_b \tag{10}$$

Where J is the hydraulic gradient in the x-direction, and $J=-\frac{dh}{dx}$.

We can write Eq.(10) as:

$$y_b=\frac{\tau_0}{\rho g(J-\sin\theta)} \tag{11}$$

Substitute Eq.(9) and Eq.(10) into Eq.(5), there results:

$$\frac{du}{dy}=-\frac{J}{\mu}(y+y_b) \tag{12}$$

Integrating the Eq.(12) from -b/2 to y (y is less than or equal to -y_b), using u=0 at y= -b/2, the calculation is:

$$u=\frac{1}{2\mu}\rho g(J-\sin\theta)\left[\frac{b^2}{4}-y^2-2y_b\left(y+\frac{b}{2}\right)\right] \tag{13}$$

When y= -y_b, we can get the velocity of plug flow u_b:

$$u_b=\frac{1}{2\mu}\rho g(J-\sin\theta)(\frac{b}{2}-y_b)^2 \tag{14}$$

Combining the Eq.(11), in the end, we can acquire the average velocity $\bar{u}$ of Binghamian grouts flowing between two slantwise parallel plates of infinite length:

$$\bar{u}=\frac{gb^2}{12\nu}(J-\sin\theta)-\frac{b\tau_0}{4\nu\rho}+\frac{\tau_0^3}{3\nu b\rho\gamma^2(J-\sin\theta)^2} \tag{15}$$

Where ν is the coefficient of kinematical viscosity of grout, and $\nu=\mu/\rho$, γ is specific weight.

If grouts penetrate from the upper part of crack to the lower part, we can easily acquire:

$$\bar{u}=\frac{gb^2}{12\nu}(J+\sin\theta)-\frac{b\tau_0}{4\nu\rho}+\frac{\tau_0^3}{3\nu b\rho\gamma^2(J+\sin\theta)^2} \tag{16}$$

Eq.(15) and Eq.(16) are the velocity formulas of Binghamian grouts in single slantwise fracture when the effects of grouts gravity were taken into account.

If we neglect the effects of gravity of grouts, or when the fracture is level, then Eq.(15) and Eq.(16) can be simplified to:

$$\bar{u}=(\frac{gb^2}{12\nu}-\frac{b\tau_0}{4\nu\rho J}+\frac{\tau_0^3}{3\nu b\rho\gamma^2J^3})J$$

$$= kJ \tag{17}$$

Where $k = \dfrac{gb^2}{12\nu} - \dfrac{b\tau_0}{4\nu\rho J} + \dfrac{\tau_0^3}{3\nu b\rho\gamma^2 J^3}$.

Eq.(17) is the same as formula referred by Yang Mi-jia[7]. But he thought ν is the dynamic viscosity, in fact, ν should be kinematical viscosity.

Thus, average flow quantity of grouts unit time $\overline{q}$ is:

$$\overline{q} = \overline{u}b = \frac{gb^3}{12\nu}J - \frac{b^2\tau_0}{4\nu\rho} + \frac{\tau_0^3}{3\nu\rho\gamma^2 J^2} \tag{18}$$

If initial shear strength is neglected, that is, τ_0 is equal to zero, then Eq.(18) can reduce to:

$$\overline{q} = \frac{gb^3}{12\nu}J \tag{19}$$

The above formula is the flow equation of Newton fluid in single smooth and horizontal fracture.

3 ACADEMIC ANALYSIS FOR PENETRATION LAW OF BINGHAMIAN GROUTS

On the basis of Eq.(16), analyzing the penetration law of Binghamian grouts in single smooth crack. The calculated results are shown in Fig.2 to Fig.7. Parameters adopted during calculating are listed in Table 1.

Table 1 Calculated parameters

Sort	g /N/m^2	b /mm	ρ /kg/m^3	θ /°	τ_0 /Pa	ν /Pa.s	h /m
Fig. 2	9.8	1	1350	30	13	0.028	
Fig. 3	9.8	1	1350		13	0.028	100
Fig. 4	9.8		1350	30	13	0.028	100
Fig. 5	9.8	1	1350	30	13		100
Fig. 6	9.8	1	1350	30		0.028	100
Fig. 7	9.8	1		30	13	0.028	100

Fig.2 shows the curve of flow velocity versus time when grouting pressure *h* changes. From the Fig.2, we can find that, with the development of time, the velocity of grouts gradually decay, and the higher grouting pressure is, the bigger velocity of grouts is. It is proved, the greater pressure is, and the further grouts spread.

Fig.3 shows the curve of flow velocity versus time when fissure inclination change. The result shows, the fissure inclination has no evident relation with velocity of grouts. When the fissure is horizontal, the initial velocity of grouts is the greatest. When the fissure inclination is equal to 30 degrees, the later flow velocity is the greatest. It seems to indicate that, with the increase of fissure inclination, the resistance acting on the flow core also increases.

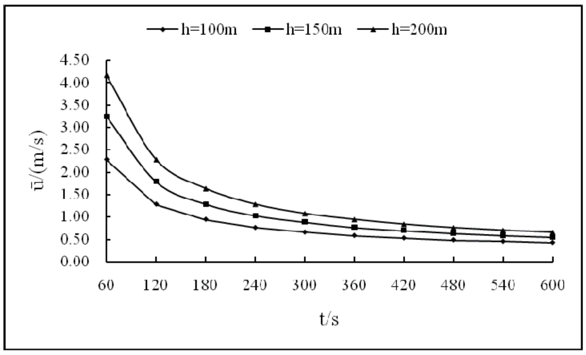

Fig. 2 Flow velocity versus time when grouting pressure changes

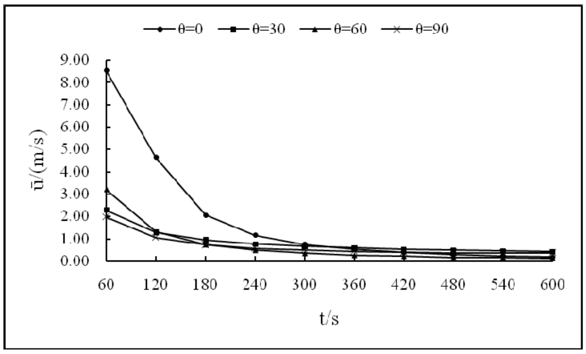

Fig.3 Flow velocity versus time when fissure inclination changes

It is obvious that we can almost neglect the fissure inclination when using the model to simulate grouting in fractured rock mass.

Fig.4 shows that, under the same grouting pressure, the wider fissure width is, and the slower flow velocity is, and vice versa. The results displayed in Fig.5 indicate that, with the increase of viscidity of grouts, the average flow velocity gradually reduces. It will have a influence on radius of diffusion and groutability. It indicates that, the greater initial shear strength is, and the faster grouts flow as shown in Fig.6. On the contrary, the smaller initial shear strength is, and the slower grouts flow.

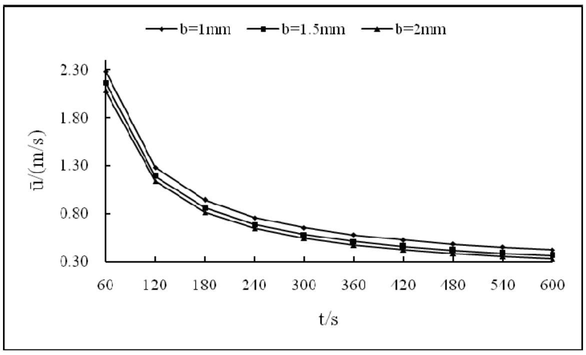

Fig.4 Flow velocity versus time when fissure width changes

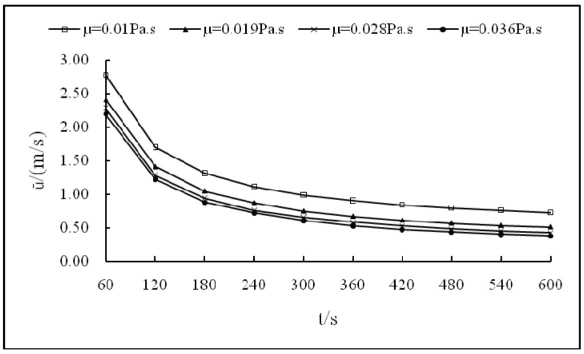

Fig.5 Flow velocity versus time when grouts viscosity changes

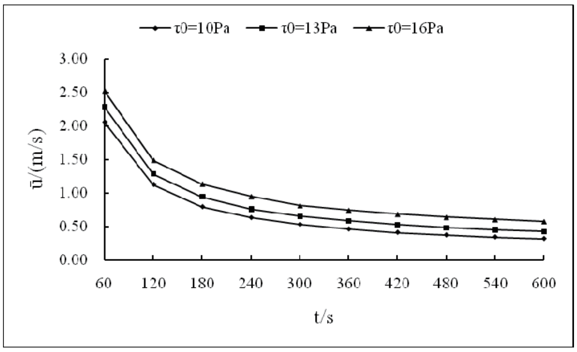

Fig.6 Flow velocity versus time when initial shear strength changes

Fig.7 shows the curve of flow velocity versus time when grouts density changes. From the Fig.7, we know that flow velocity is inversely proportional to grouts density under the same grouting pressure.

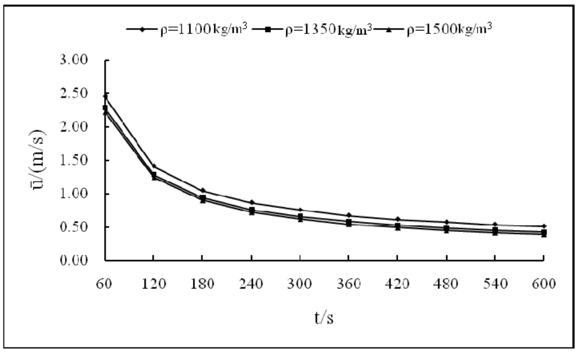

Fig.7 Flow velocity versus time when grouts density changes

4 CONCLUSIONS

This paper has presented a flow model of Binghamian grouts in single slantwise fracture when the effects of grouts gravity were taken into account. If the inclination is ignored, then the model is the same as the model referred by Yang Mi-jia(7). After a series of calculations, the results show:

1. With the development of time, the flow velocity of grouts gradually slow and becomes gently. The stronger pressure of grouting is, and the greater flow velocity is. It is evident that the grouts will spread longer under greater pressure.

2. The fissure inclination has no evident relation with velocity of grouts. In addition, the steeper the fissure is not, the greater the flow velocity is.

3.Under the circumstance of the same other parameters, the wider the fissure width is, the slower the flow velocity is; the greater the viscosity and the density are, the slower flow velocity is; but the velocity of flow will quicken if the initial shear strength gradually increase.

The advantage of the model is that the influences of fracture inclination on penetration law of grouts are taken into account. The lack of the model is that the influences of water, gas and roughness on penetration law are ignored. We expect all of these problems can be resolved in later research.

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REFERENCES

(1) LIU Jia-cai. Study on penetration radius in crack grouting. Scientific research papers in China Institute of Water Resources and Hydropower Research, Beijing(In Chinese), (1982), p186-195.
(2) Baker C. Comments on paper’ Rock Stabilization in Rock Mechanics’. Muler, Springer-Verlag NY, (1974).
(3) Nonveiller E. Grouting, theory and practice. Amsterdam, Elsevier, (1989).
(4) Lombardi G.. The role of the cohesion on cement grouting of rock. In Proc. of the 15th Congress on Large Dams, Lausanne, International Commission on Large Dams(ICOLD), (1985), p235-261.
(5) Amadei B and Savage W Z. An analytical solution for transient flow of Bingham viscoplastic materials in rock fractures. International Journal of Rock Mechanics and Mining Sciences, Vol.38, No.2, (2001), p285-296.
(6) Jamal Mohammed Saleh(2002). Fluid flow handbook. Mc Graw-Hill Education, London.
(7) YANG Mi-jia, HE Yong-nian, CHEN Ming-xiong. Law of grouting penetrating through fracture network of rock mass, Journal of Hydraulic Engineering, Beijing(In Chinese), No.7, (2001), p41-46.

傾斜した亀裂内でビンガム流体状グラウトの流れモデル

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概要
平行板間の Navier-Stokes の方程式により、ビンガム流体状グラウトの運動方程式を滑らかで傾斜した亀裂内について導出した。モデルは流速が時間とともに減少することを示している。また、圧力が増加すると、流速が増加し、結果として、ビンガム流体状グラウトはさらに浸透する。ビンガム流体状グラウトの流速は亀裂の傾斜との関係はない。さらに、同じパラメータ環境では、グラウトの粘性が大きくなると、流速は小さくなり、ビンガム流体状グラウトの密度が大きくなると、流速は小さくなり、それらの逆もまた成り立つ。

キーワード：亀裂性塩盤体、グラウチング、流れモデル、ビンガム流体状グラウト

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